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A Systematic Study of X-Ray Emission from Active Semi-Detached Systems

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This grant funded ROSAT PSPC observations of six Algol-type binary stars, chosen to have secondary stars with relatively early spectral types and signs of superionized circumstellar gas in their ultraviolet spectra. All six targets were observed, and the data were received and analyzed.

Personnel involved in the proposal were Dr. Richard Wade (Penn State, PI), Dr. Ronald S. Polidan (GSFC, Co-I), and Dr. Guy Stringfellow (Penn State, postdoctoral researcher). Dr. Stringfellow moved to the University of Colorado in October 1995. No publications resulted from this grant, although the conclusions reached were presented in poster form at the Maryland conference on "Evolution of X-ray Binaries" in October 1993. (It was expected that a journal article would be prepared, incorporating not only the X-ray analysis but a correlation of X-ray properties with ultraviolet, optical, and orbital properties of the binaries, so no contributed paper was written for the conference volume. In spite of efforts to assemble and discuss these diverse data, continuing into 1996, it proved infeasible to coordinate the activities of people at three different institutions and complete the larger analysis.) The X-ray results are discussed in the following paragraphs and are presented in tabular form, along with some auxiliary data, at the end of this report.

Four of the six targets were easily detected by the PSPC and two observations resulted in non-detections or upper limits. The non-detections were of λ Tau and V356 Sgr. The spectra of the four detected sources, U CrB, TX UMa, CX Dra, and TT Hya, were fitted with the Raymond-Smith code and were found to require two-temperature models. Temperature parameters, interstellar columns, emission measures, and luminosities were derived. Three sources, U CrB, TX UMa, and CX Dra, are among the most X-ray luminous Algols known (excepting Algol itself during flares), while the fourth source, TT Hya, is the least luminous of the detected systems.

The PSPC data were examined for time variability. Observations during eclipse do not show any obvious diminution of X-ray flux, suggesting that the X-rays are not produced in a compact region between the stars. No variability was found on other timescales among the four detected targets.

Auxiliary data concerning the binary systems, their periods, masses, fractional radii, distances, colors, reddenings, etc, were collected, but as mentioned above the envisioned discussion of the X-ray data in this context was not carried out. It is hoped that such a discussion will eventually occur, and perhaps bear on the question of whether the X-ray emission in Algols invariably results from coronal activity on the secondary star, or whether colliding winds, or gas stream interactions may play a role. Our data, present in the ROSAT archive, have already contributed to a preliminary discussion of X-ray systematics of Algol and RS CVn binaries (Singh, Drake & White 1996, AJ 111, 2415), although these authors did not carry out a spectral analysis.

Table 1

Log of *ROSAT* Observations

Target	UT Dates (Year/Day)	Exposure Time[a] (ksec)	Net Counts	Net Count Rate (per ksec)
U CrB	1992/225–232	19.0	1280	67
TX UMa	1993/150–152	14.7	1620	110
CX Dra	1992/333	3.6	340	94
TT Hya	1993/1–5	10.6	200	19
V356 Sgr	1993/99–104	10.5	<15[b]	<2
λ Tau	1993/61	3.1	<9[b]	<3

Notes. (a) Exposure Time indicates "good" time on target, accepted for analysis. (b) Upper limits on net counts and count rates are quoted as 3× the standard deviation of the background in the detector circle.

Table 2

Two-component Raymond-Smith Fits to PSPC Spectra

	U CrB	TX UMa	CX Dra	TT Hya
$\log N_H$ (cm^{-1})	20.3±0.2	19.8±0.3	19.9±0.5	20.0±0.6
kT_{low} (keV)	0.20±.02	0.24±.04	0.24±.10	0.28±.10
kT_{high} (keV)	1.06±.05	1.06±.05	0.95±.06	0.67±.20
$\log \mathrm{EM}_{low\ kT}$ (cm^{-3})	53.5	53.2	53.1	52.0
$\log \mathrm{EM}_{high\ kT}$ (cm^{-3})	53.9	53.7	53.6	52.2
$\log \mathrm{EM}_{total}$ (cm^{-3})	54.0	53.8	53.7	52.4
χ^2 (27 d.o.f.)	20	13	25	27

Derived X–Ray Properties

	U CrB	TX UMa	CX Dra	TT Hya
$\log L_x$ (erg s^{-1})[a]	31.32	31.09	31.09	29.85
Luminosity Ratio[b]	0.51	0.43	0.41	0.31
$\log R_x$ (Primary L_{bol})[c]	–4.9	–4.6	–6.0	–5.2
$\log R_x$ (Secondary L_{bol})[c]	–3.6	–3.8	–4.4	–4.8

Notes. (*a*) L_x is the unabsorbed X-ray luminosity (0.11–2.24 keV) assuming isotropic emission. (*b*) Unabsorbed luminosity ratio $\equiv L(0.11 - 0.47\ \mathrm{keV})/L(0.47 - 2.24\ \mathrm{keV})$. (*c*) $R_x \equiv L_x/L_{bol}$ using L_{bol} of either the primary or secondary star.

Table 3

Properties of the Sample

	U CrB	TX UMa	CX Dra	TT Hya	V356 Sgr	λ Tau[a]
V magnitude	7.66	7.06	5.68	7.25	6.84	3.37
Spectral Types	B6 V	B8 V	B2.5 V	B9.5 V	B3 V[b]	B3 V
	F8 III	F5-G0 IV	F2-F5 III	K0 III	A2 II	A4 IV
Orbital Period (d)	3.45	3.06	6.70	6.95	8.90	3.95
Eclipse type	P	P	N	T	T	P
Orbital Inclination	80°	81°	53°:	84°	90°	76°
Masses ($M_\odot$)	4.8, 1.4	3.6, 1.1	6.2, 1.5	2.25, 0.41	12.1, 4.7	7.2, 1.9
Radii ($R_\odot$)[c]	3.3, 4.7	2.3, 4.0	5, 7.4	1.90, 4.9	6.0, 13.2	6.4, 5.7
$\log(a_1 + a_2)$ (cm)	12.1	12.0	12.3	12.2	12.5	12.2
Effective Temp (K)	14,800	12,900	19,500	9,800	12-30,000[b]	18,000
	6,000	~6,000	6,500	4,750	8,600	8,300
Luminosity ($L_\odot$)	470	130	3250	31	2400-12500[b]	3850
	24	20	100	14	960	120
Secondary $v \sin i$ (km s^{-1})	66	68	63	43	80	80
Secondary $(B-V)$	+0.43:	+0.58	+0.52:	+0.97	0.01	0.08
Distance (pc)	450	315	300	193	750:	132
$\log N_H$ (cm^{-2})[d]	20.3	<20.0	<20.3	<20.0	21.2	<20.3

Notes. (*a*) λ Tau is a triple system. The third star is a K dwarf, the outer orbital period is 33 days (non-eclipsing). (*b*) The primary star of V356 Sgr is critically rotating. . (*c*) Radius of the secondary star is the average of the "pole" and "side" radii of the Roche lobe. (*d*) N_H derived from UV/optical/radio measure.